Effect of the impurity injection on plasma confinement in T-10 tokamak

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Impurity injection has been demonstrated as an attractive tool to increase a plasma stored energy and decrease confinement degradation with the heating power in several tokamaks [1]. It was shown in [2], that in experiments with Ne puffing the plasma energy content depends rather on radiation losses than on plasma density (Fig.1).

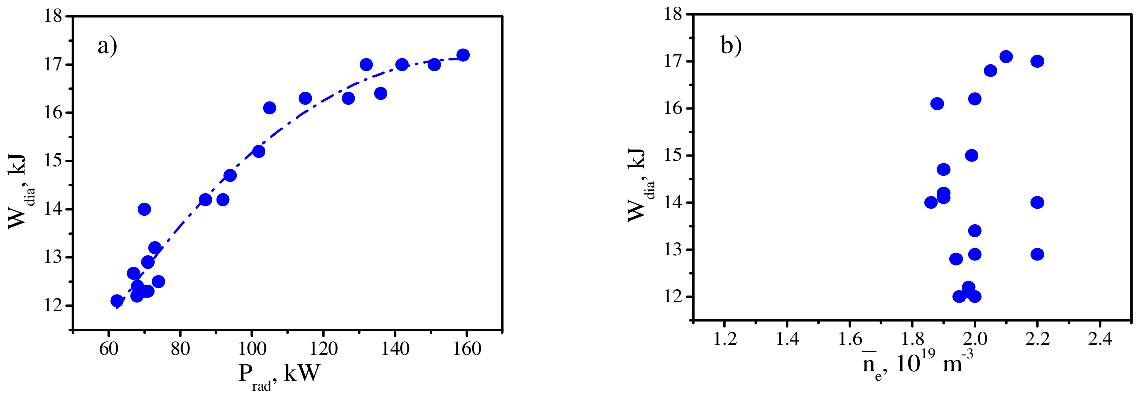

Figure 1. Increase of the plasma energy content (a) with the increase of the radiation losses in the regime with Ne puffing observed in spite of the absence of the density dependence (b) [2].

Explanation of this effect is given in [2] basing on the plasma self-organization paradigm [3 and ref. therein]. This approach assumes the following main postulates: i) there are stable self-consistent plasma pressure profiles which correspond to the minimum of the plasma free energy; ii) under the external impact the realization of these profiles is governed through the turbulent activity; iii) mechanism of the plasma self-organization and confinement of the turbulent plasmas can be explained in frames of the thermodynamic approach [3,4]. In accordance with [3], the heat flux Γ can be written in the form $\Gamma=-(\theta/\xi)\cdot grad(p)+p\cdot(\theta/\xi)\cdot k_0$, where p is the plasma pressure profile, $k_0=grad(p_0)/p_0$, p_0-pressure profile corresponding to the condition of self-organization. The value of θ/ξ is equivalent to the heat conductivity, χ. Modeling performed in [2] showed that χ increases with the increase of the heat flux as $\chi \sim \Gamma^{2/3}$, the increase of the radiation losses on the plasma periphery leads to the global decrease of χ. It can be expected that not only absolute value of radiation losses but their location and width of the distribution profile should play a role in this mechanism. Under T-10 conditions radiations from He and Ne are strongly separated in space: at 0.6<r/a<1 in experiments with Ne puffing and at 0.8<r/a<1 with He puffing. That is why experiments with He and Ne could be helpful to find the experimentally proven dependence of χ on the heat flux Γ.

Results discussed here have been obtained in T-10 (a=0.3-0.33 m, R=1.5 m) in regimes with tungsten limiters after lithization in a plasma configuration with q_L=3-3.5 in ohmic discharges and in regimes with ECRH (0.5-0.8 MW). Impurity gas (Ne or He) has been injected to the deuterium plasmas during quasi steady-state phase of the discharge. Typical experimental scenario is presented in Figure 2. It is necessary to note that in all cases in discharges with the impurity injection the feedback control of plasma density has been switched–off, scenario of deuterium puffing was defined from the reference shot (marked by blue traces in Figure 2) and fixed.

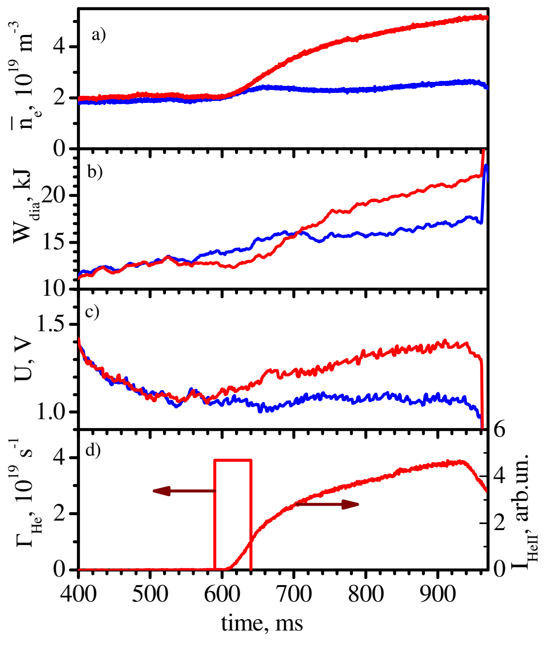

Figure 2. Typical scenario of the experiment with impurity injection. Blue traces – reference shot without impurity injection, red traces – shot with helium injection. a) – line averaged plasma density, b) – stored energy, c) – loop voltage, d) – helium flux and HeII line intensity.

Results obtained in ohmic regime and in regime with ECRH are presented in Figure 3 and 4 respectively. It is seen that the impurity injection (both Ne and He) leads to the increase of the plasma density and plasma energy content. In the regimes with Ne puffing the increase of the plasma density and plasma energy content is higher at the same level of Ne and He particle flux. The effect of the density and stored energy increase depends on the puffing intensity and on the parameters of the regime before injection. If the impurity flux is increased or the impurity gas is injected into the discharge with initially high level of radiation losses (due to the presence of C and O impurities), P_{rad}>150 kW and $\bar{n}_e > 3\cdot10^{19}\,m^{-3}$, the effect of the He and Ne puffing saturates in spite of the further increase of the impurity flux. The increase of the radiation losses in a whole plasma was observed after the impurity injection. W accumulation seems to be more relevant explanation of the rise of the core radiation, however this question is still under investigation.

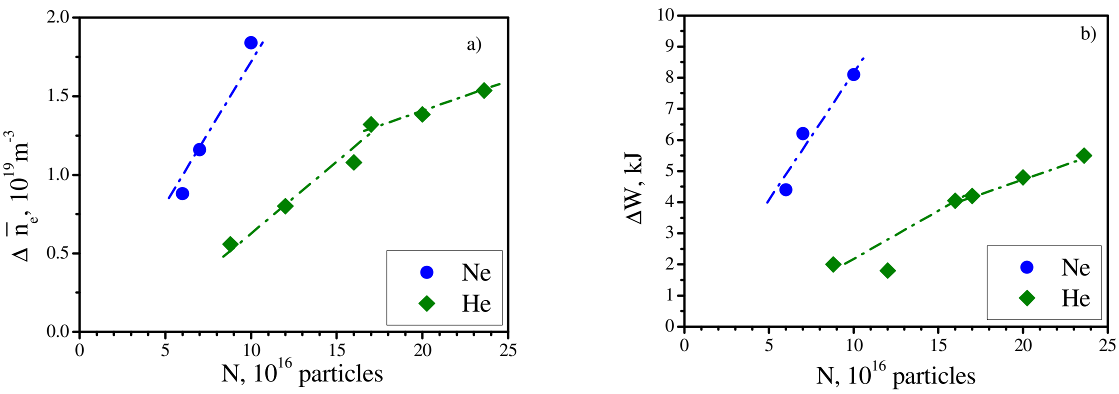

Figure 3. Dependence of the density increase (a) and plasma stored energy increase (b) on the impurity puffing intensity in ohmic discharges.

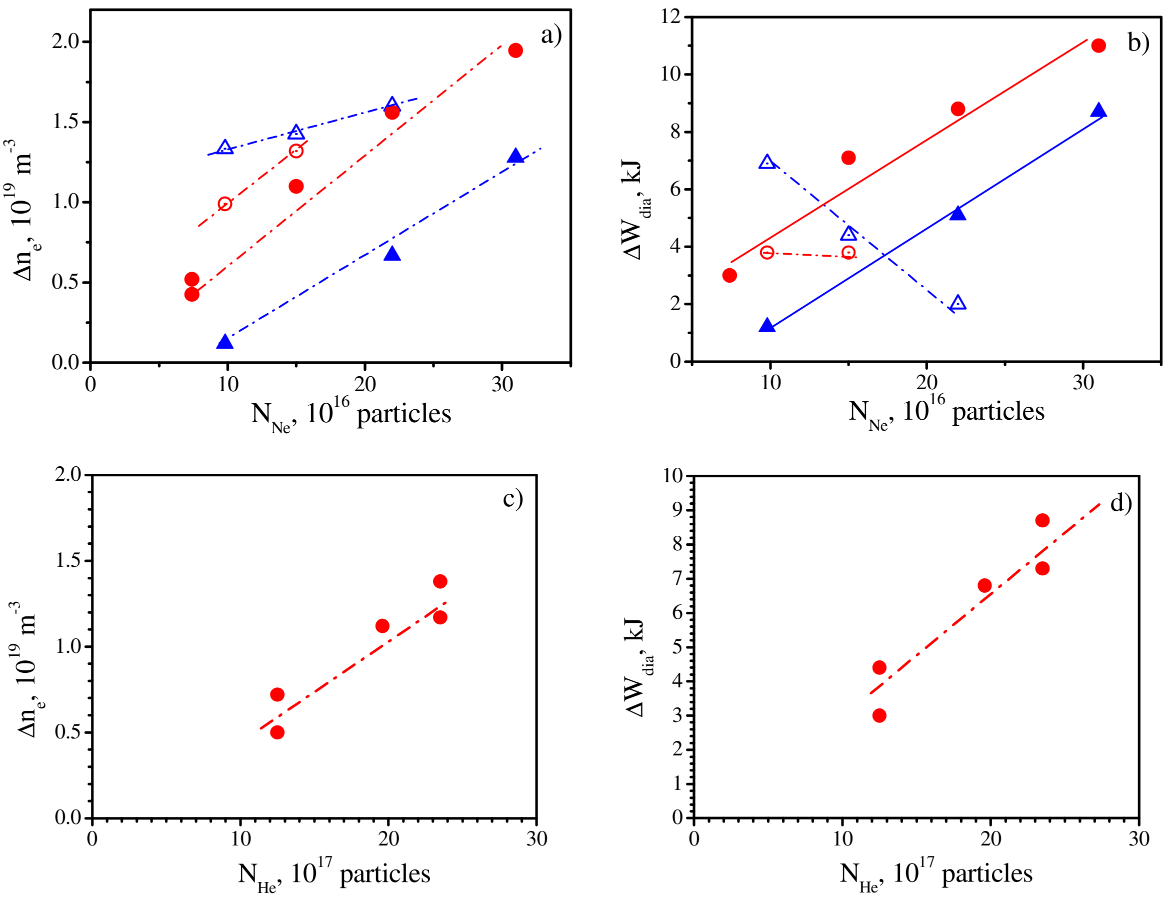

Figure 4. Dependence of the line averaged density increase (plots a) and c)) and plasma stored energy increase (plots b) and d)) on the intensity of impurity puff in discharges with ECRH and pulse impurity puffing (pulse duration Δt=2 ms). Circles – P_{ECRH}=0.5 MW, triangles – P_{ECRH}=0.8 MW. Closed and open points characterize regimes with different parameters before impurity injection: closed points – low density and radiation losses, open points –respectively high density and radiation losses.

It is important to note that due to its deep penetration the neon puffing easily led to the MHD mode development, which restricted the maximal value of the used neon flux. In contrast the increase of MHD activity was not observed in a whole experimental range in discharges with He puffing. Moreover, the limit density value appeared to be higher in regimes with He puffing (estimated He flux did not exceed 10% of total particle flux) than one obtained in deuterium discharges without impurity puffing. Two discharges with similar line averaged density evolution are shown in Figure 5. In the discharge marked by blue curves the density increase is caused by the increased deuterium puffing started at t=590 ms. In the discharge marked by red curves the density increase is caused by the helium puffing (without the increase of the deuterium puffing). Comparison of the m=2 mode amplitude is presented in Figure 5,b and demonstrates better stability of the discharge with helium puffing, which can be explained by the higher electron temperature on the plasma periphery.

So, He and Ne impurity puffing both led to the plasma density and stored energy rise. The value of the effective plasma charge was changed in the regimes with Ne puffing (from 1.25 up to >2 depending on the neon flux). The increase of the value of z_{eff} was not observed in experiments with He puffing. Then the effect of the confinement modification can not be explained by the change of z_{eff}. However it does not contradict to the thermodynamic approach and modeling results presented in [2]: the increase of the radiation losses leads to the decrease of the heat flux in some area and as a consequence to the change of transport coefficient χ.

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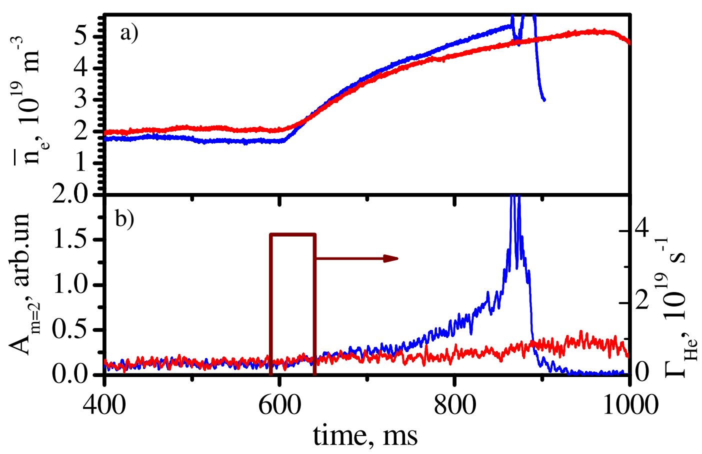

Figure 5. Traces of the plasma density (a), amplitude of m=2 MHD mode and helium flux (b). Blue curves – deuterium discharge. Density limit disruption occurs at t=865 ms. Red curves – discharge with helium puffing.

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